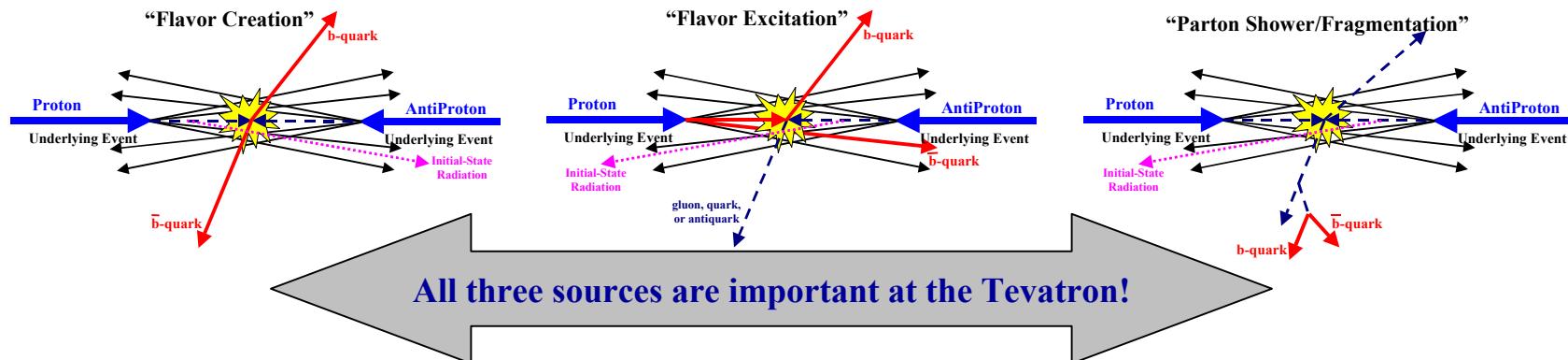




b-Quark Production at the Tevatron



- I believe it is important to have good “leading-log” order QCD Monte-Carlo model predictions of collider observables. The “leading-log” QCD Monte-Carlo model estimates are the “**base line**” from which other calculations can be compared.
- I see no reason why the QCD “leading-log” Monte-Carlo models should not **qualitatively** describe heavy quark production (*in the same way they qualitatively describe light quark and gluon production*).
- We measure **hadrons & leptons (NOT quarks & gluons)** and hadronization effects are important! The QCD “leading-log” Monte-Carlo models incorporate fragmentation via “string fragmentation” or “cluster fragmentation” or “FF fragmentation” thus producing hadrons and leptons.
- At “leading-log” order the sources of b-quarks can be divided into three categories: “**flavor creation**”, “**flavor excitation**”, “**shower/fragmentation**” (*i.e. “gluon splitting”*).





b-Quark Production at the Tevatron



- I believe it is important to have good “leading-log” predictions of collider observables. These are the “base line” from which other “leading-log” calculations can be compared.
- I see no reason why the QCD Monte-Carlo models should not qualitatively describe heavy quark production.
- We measure hadrons! Hadrons are important! The QCD Monte-Carlo Models predict, how stable the estimates are, and how they compare with data.
- At “leading-log” order we want to know what the “leading-log” QCD Monte-Carlo Models predict, how stable the estimates are, and how they compare with data.

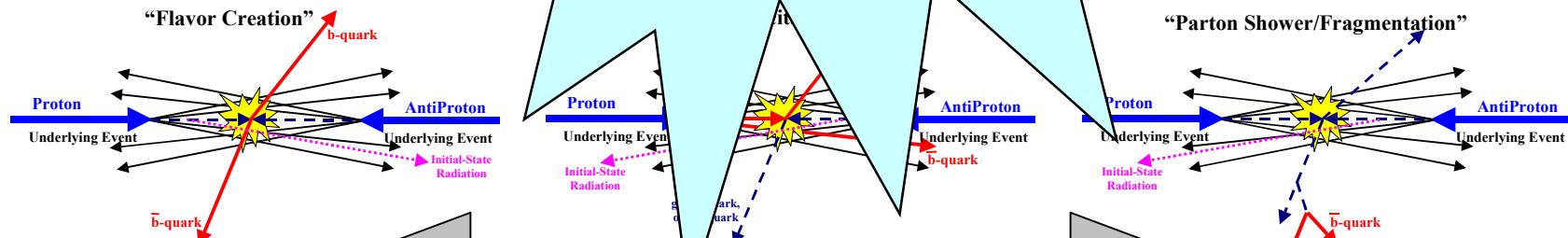
Want to know what the “leading-log” QCD Monte-Carlo Models predict, how stable the estimates are, and how they compare with data.

order QCD Monte-Carlo model “leading-log” QCD Monte-Carlo model estimates can be compared.

models should not qualitatively describe light quark and gluon production).

ionization effects are incorporate fragmentation via “string fragmentation” thus producing

current three categories: “flavor creation”, “gluon splitting”).



All three sources are important at the Tevatron!

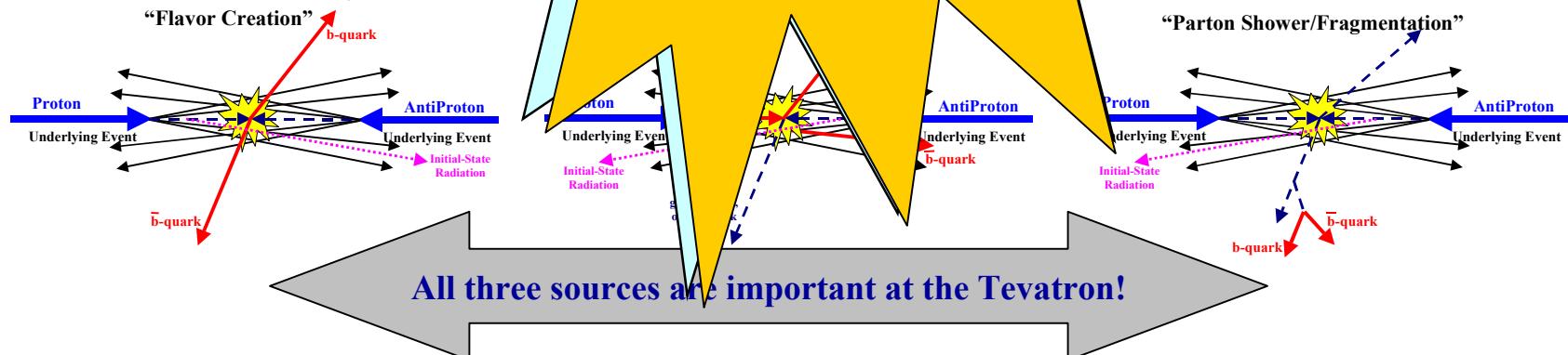


b-Quark Production at the Tevatron



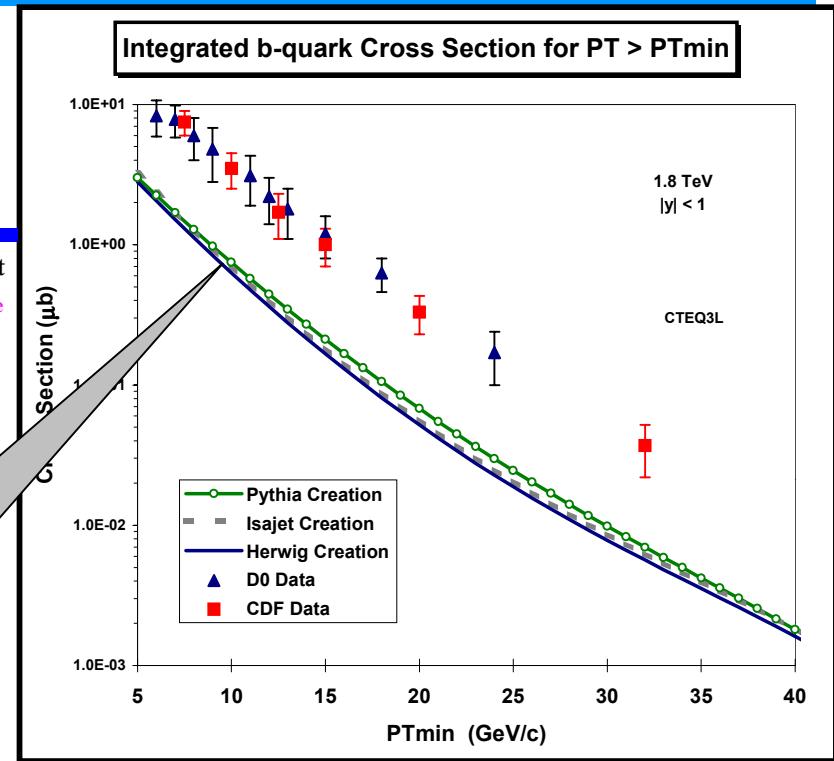
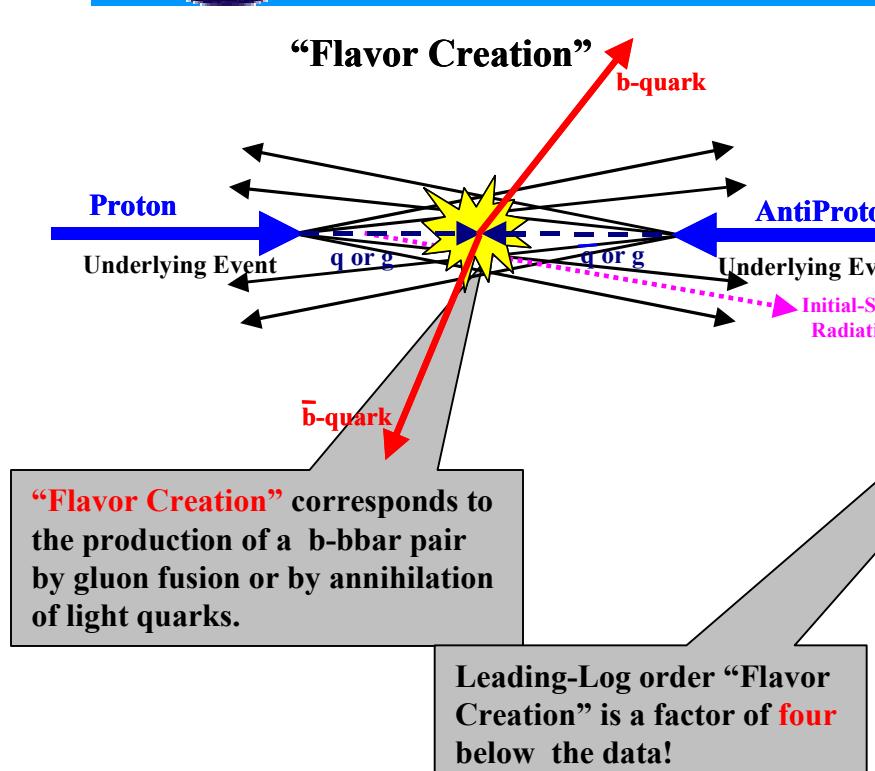
- I believe it is important to have good “leading-log” order QCD Monte-Carlo model predictions of collider observables. These “leading-log” QCD Monte-Carlo model estimates are the “base line” from which other calculations can be compared.
- I see no reason why these models should not qualitatively describe heavy quark production (*and gluon production*).
- We measure hadrons! These fragmentation effects are important! The QCD “string fragmentation” of hadrons and leptons.
- At “leading-log” order we incorporate fragmentation via “flavor creation”, “flavor fragmentation” thus producing three categories: “flavor creation”, “gluon splitting”).

Soon!... when we have beyond “leading-log” order Monte-Carlo models **with fragmentation!**





“Flavor Creation”

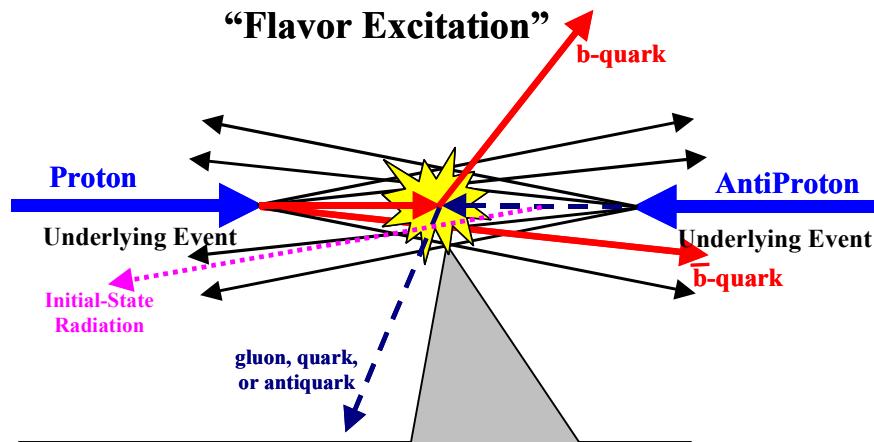


- Data from CDF and D0 for the integrated b-quark total cross section ($P_T > P_{T\min}$, $|y| < 1$) for proton-antiproton collisions at 1.8 TeV compared with the QCD Monte-Carlo model predictions of HERWIG, PYTHIA, and ISAJET for the “flavor creation” subprocesses. The parton distribution functions CTEQ3L have been used for all three Monte-Carlo models. .

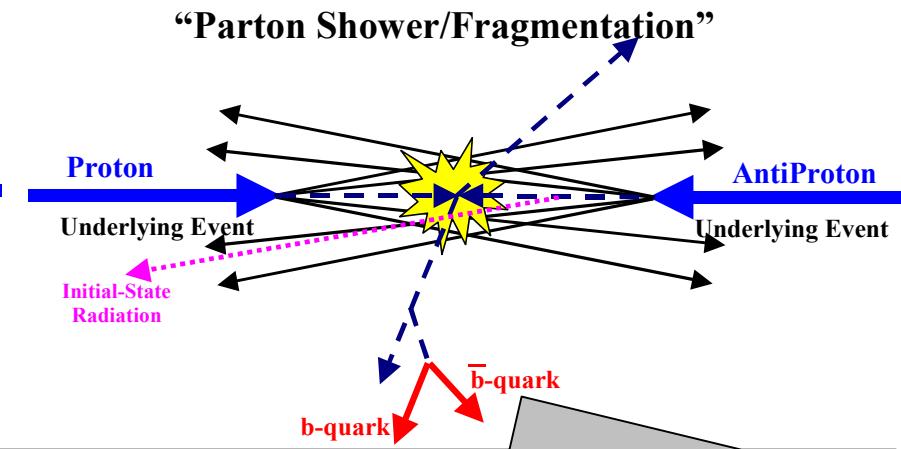


“Flavor Excitation”

“Gluon Splitting”



“Flavor Excitation” corresponds to the scattering of a b-quark (or $b\bar{b}$ -quark) out of the initial-state into the final-state by a gluon or by a light quark or antiquark.

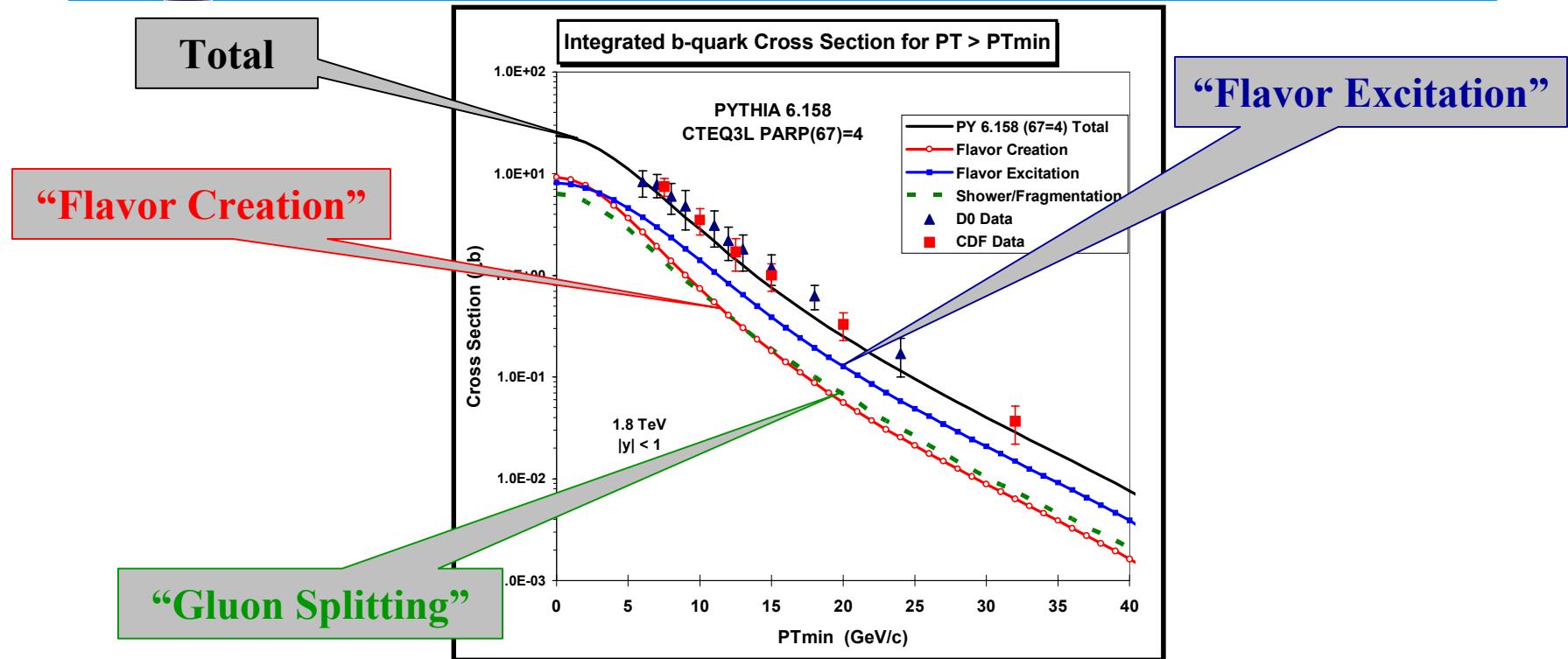


The $b\bar{b}$ -pair is created within a parton shower or during the fragmentation process of a gluon or a light quark or antiquark. Here the QCD hard 2-to-2 subprocess involves gluons and light quarks and antiquarks. This includes what is referred to as “gluon splitting”.

- “Flavor excitation” is, of course, very sensitive to the number of b-quarks within the proton (*i.e.* the structure functions).
- The Monte-Carlo models predictions for the “shower/fragmentation” contribution differ considerably. This is not surprising since ISAJET uses independent fragmentation, while HERWIG and PYTHIA do not; and HERWIG and PYTHIA modify the leading-log picture of parton showers to include “color coherence effects”, while ISAJET does not.



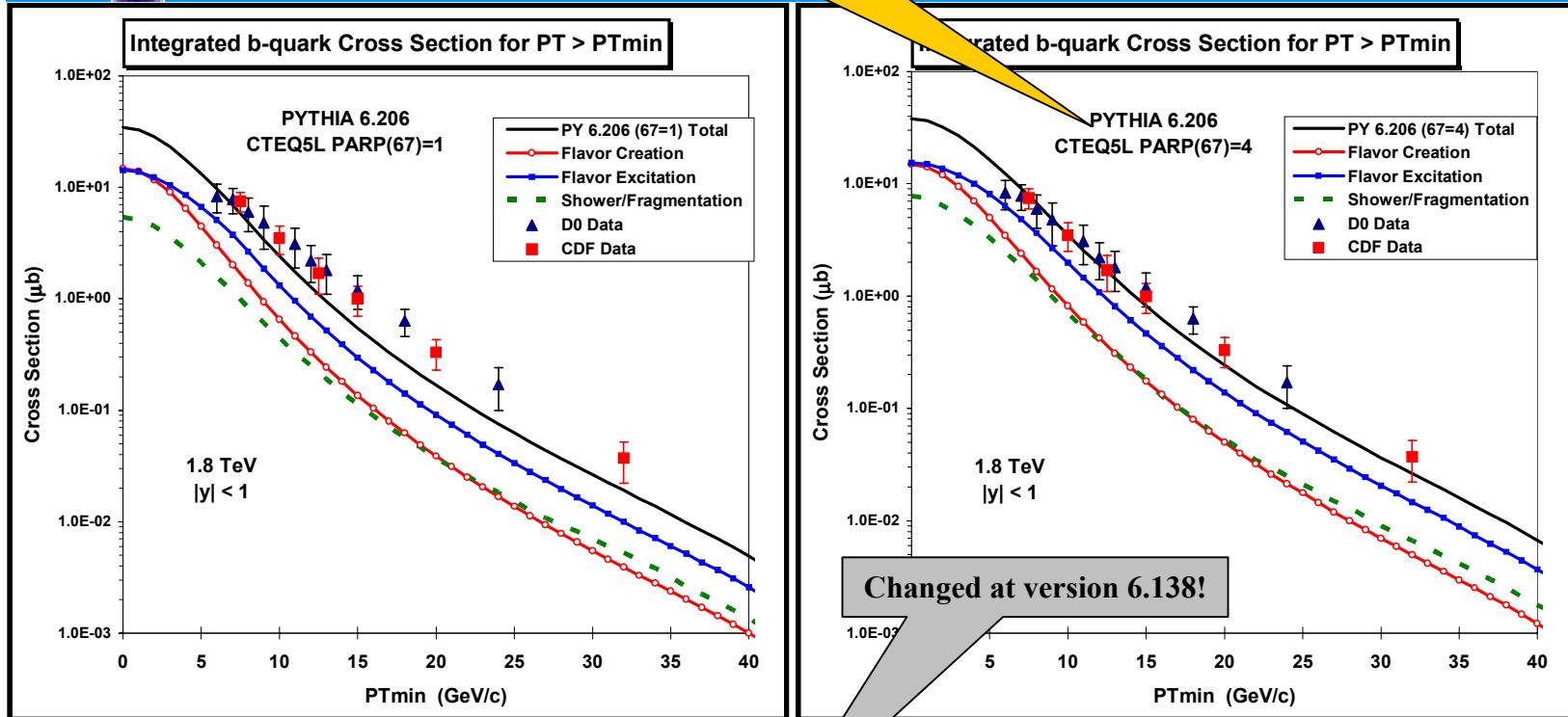
Integrated Inclusive b-Quark Cross Section



- Data on the integrated b-quark total cross section ($P_T > PT_{\text{min}}$, $|y| < 1$) for proton-antiproton collisions at 1.8 TeV compared with the QCD Monte-Carlo model predictions of PYTHIA 6.158 (CTEQ3L, PARP(67)=4). The four curves correspond to the contribution from “flavor creation”, “flavor excitation”, “shower/fragmentation”, and the resulting total.



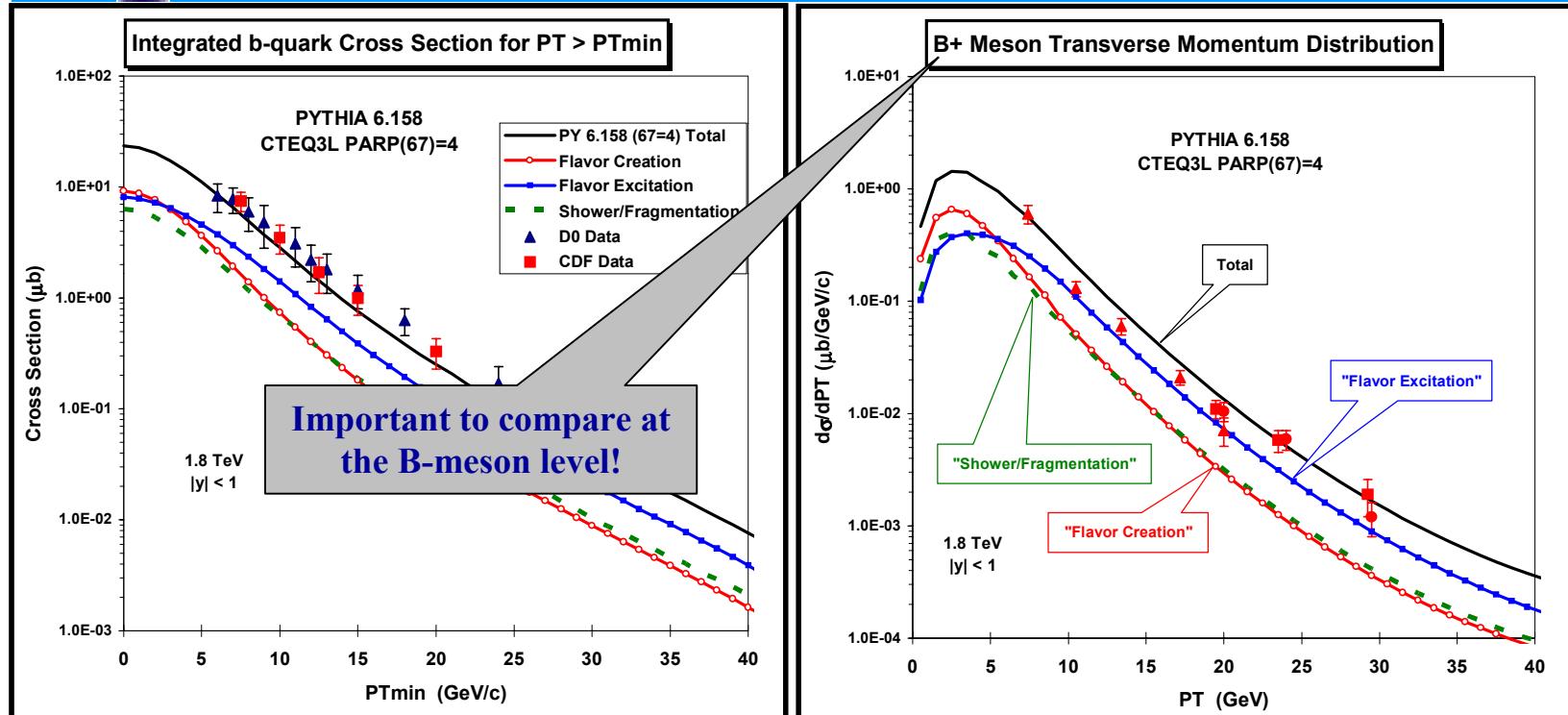
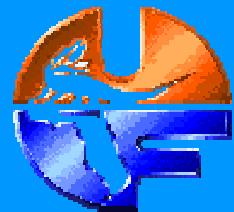
Integrated Inclusive b-Qua PYTHIA Tune A Section



- Data on the integrated b-quark total cross section ($P_T > PT_{min}$, $|y| < 1$) for proton-antiproton collisions at 1.8 TeV compared with the QCD Monte-Carlo model predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default). The four curves correspond to the contribution from flavor creation, flavor excitation, shower/fragmentation, and the resulting total. PARP(67) is a scale factor that governs the amount of large angle initial-state radiation. Larger values of PARP(67) results in more large angle initial-state radiation!



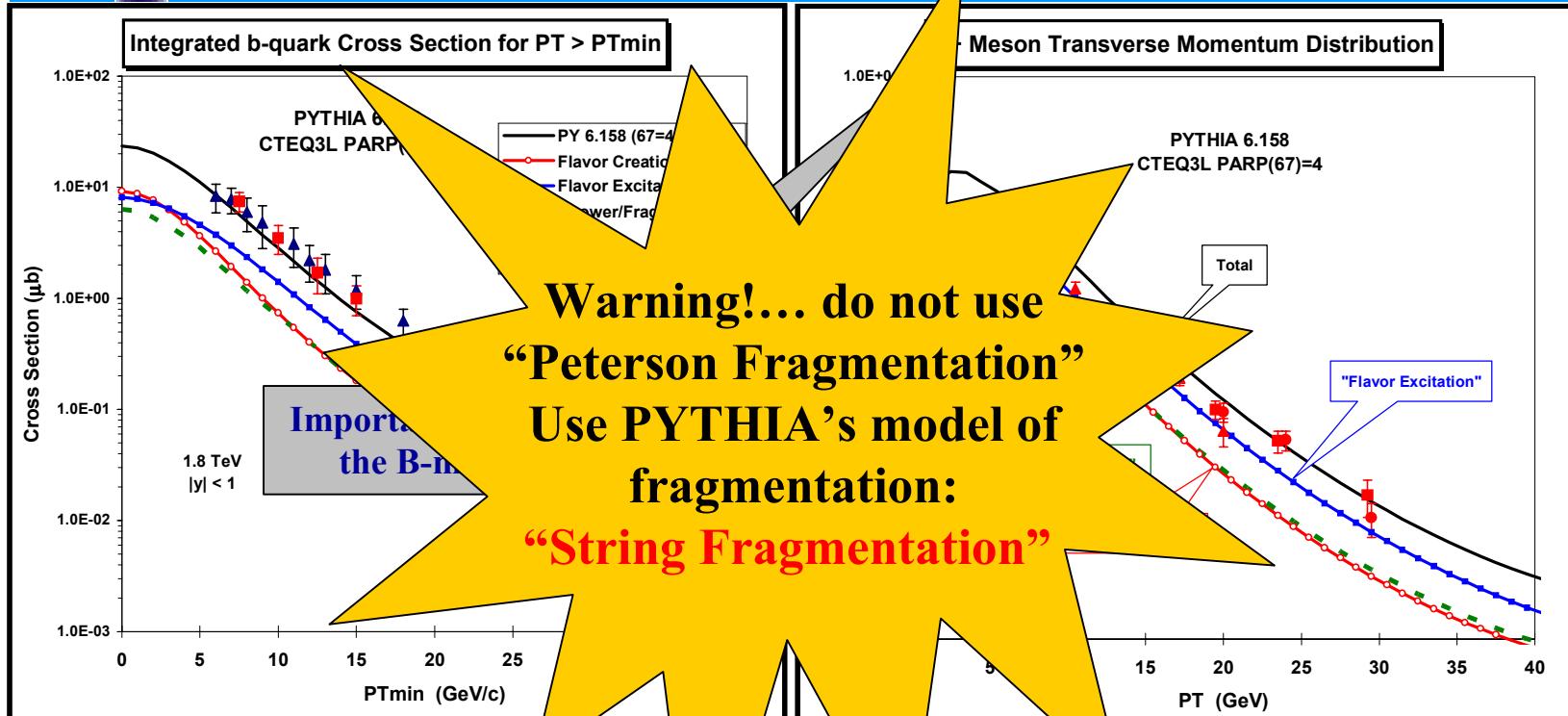
B⁺ Meson Cross Section



- Data on the **integrated b-quark cross section** ($P_T > \text{PT}_{\text{min}}, |y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of PYTHIA 6.158 (CTEQ3L, PARP(67)=4).
- Data on the **B⁺ meson differential cross section** ($|y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of PYTHIA 6.158 (CTEQ3L, PARP(67)=4).



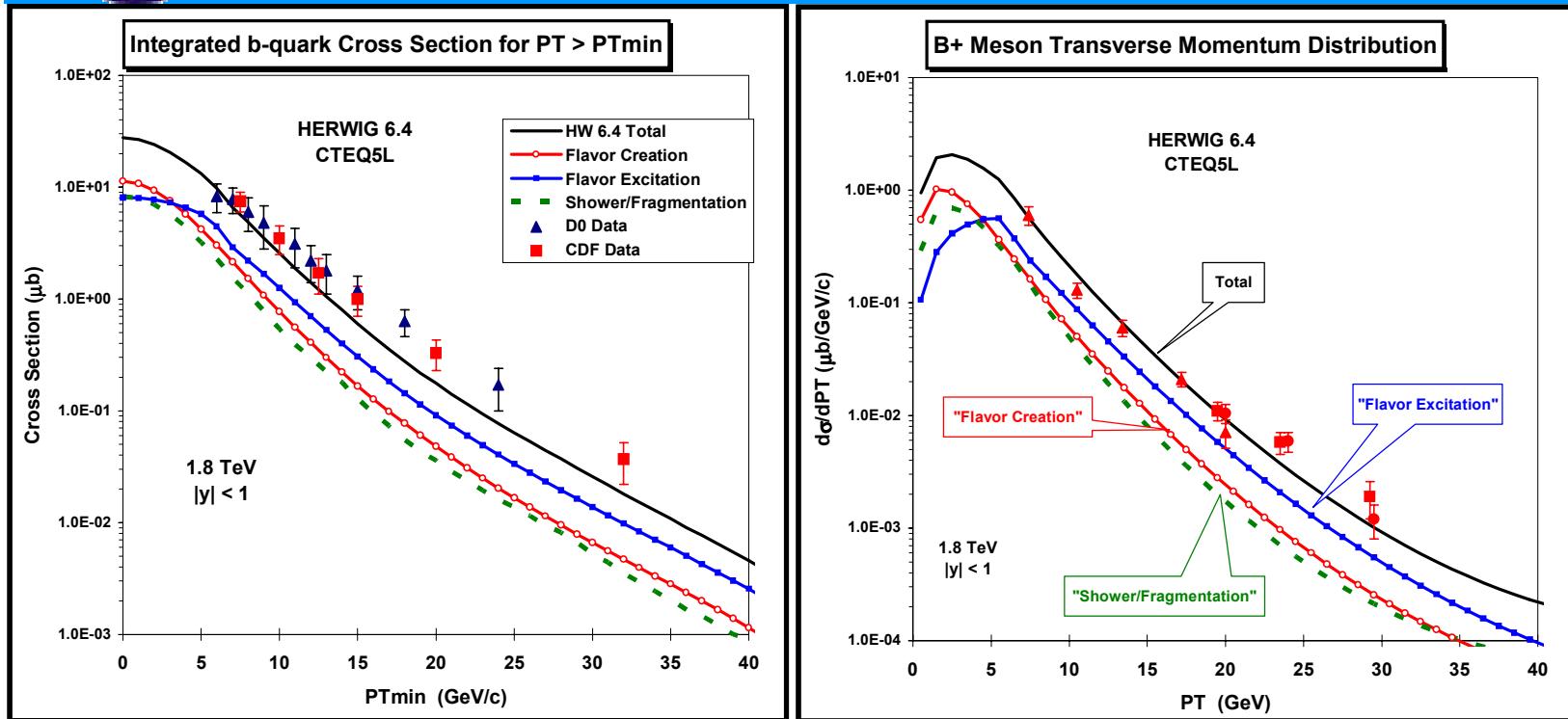
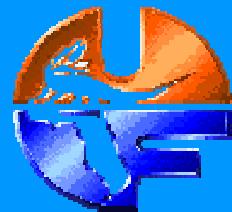
B⁺ Meson Cross Section



- Data on the **integrated b-quark cross section** ($\text{PT} > \text{PT}_{\text{min}}, |y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of PYTHIA 6.158 (CTEQ3L, PARP(67)=4).
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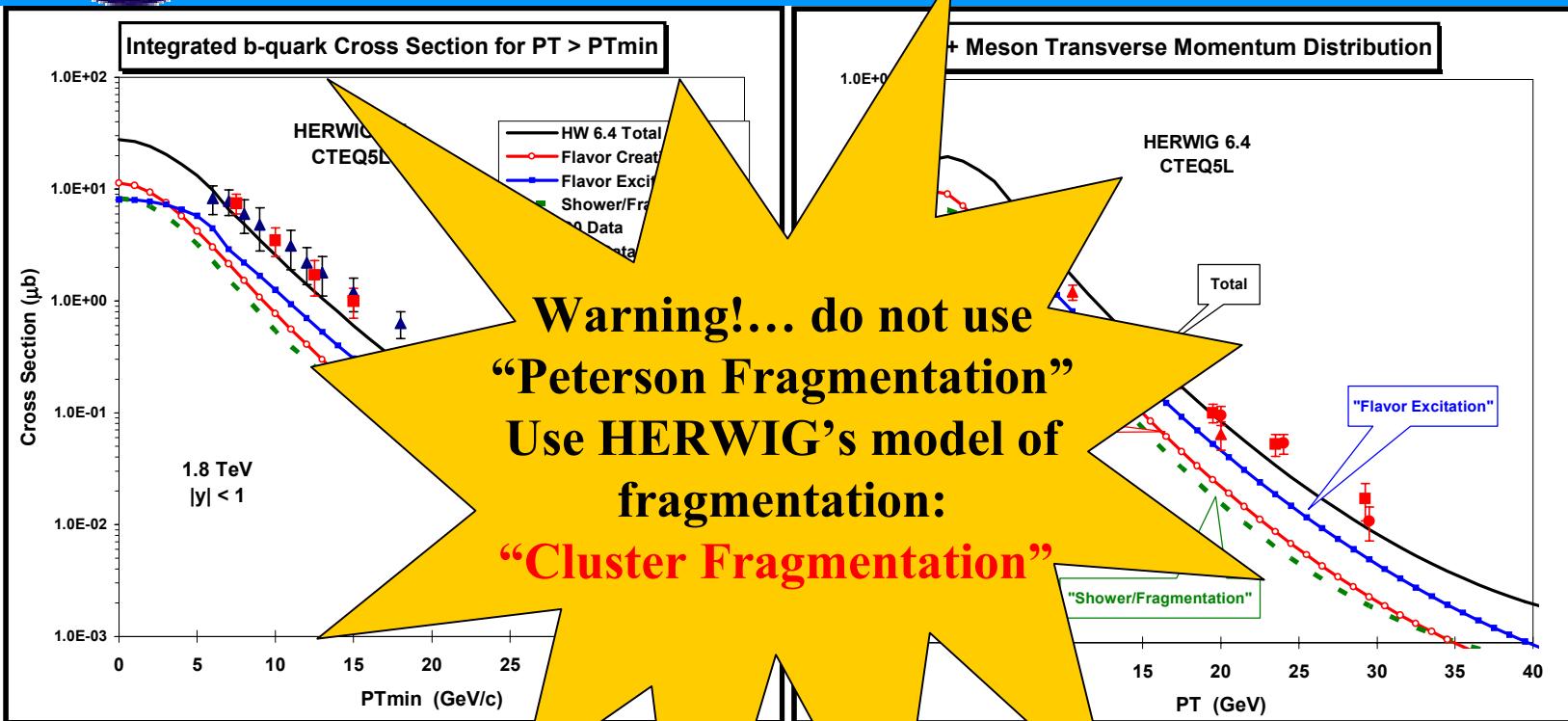
B⁺ Meson Cross Section



- Data on the integrated b-quark cross section ($P_T > P_{T\text{min}}, |y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of HERWIG 6.4 (CTEQ5L).
- Data on the B⁺ meson differential cross section ($|y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of HERWIG 6.4 (CTEQ5L).



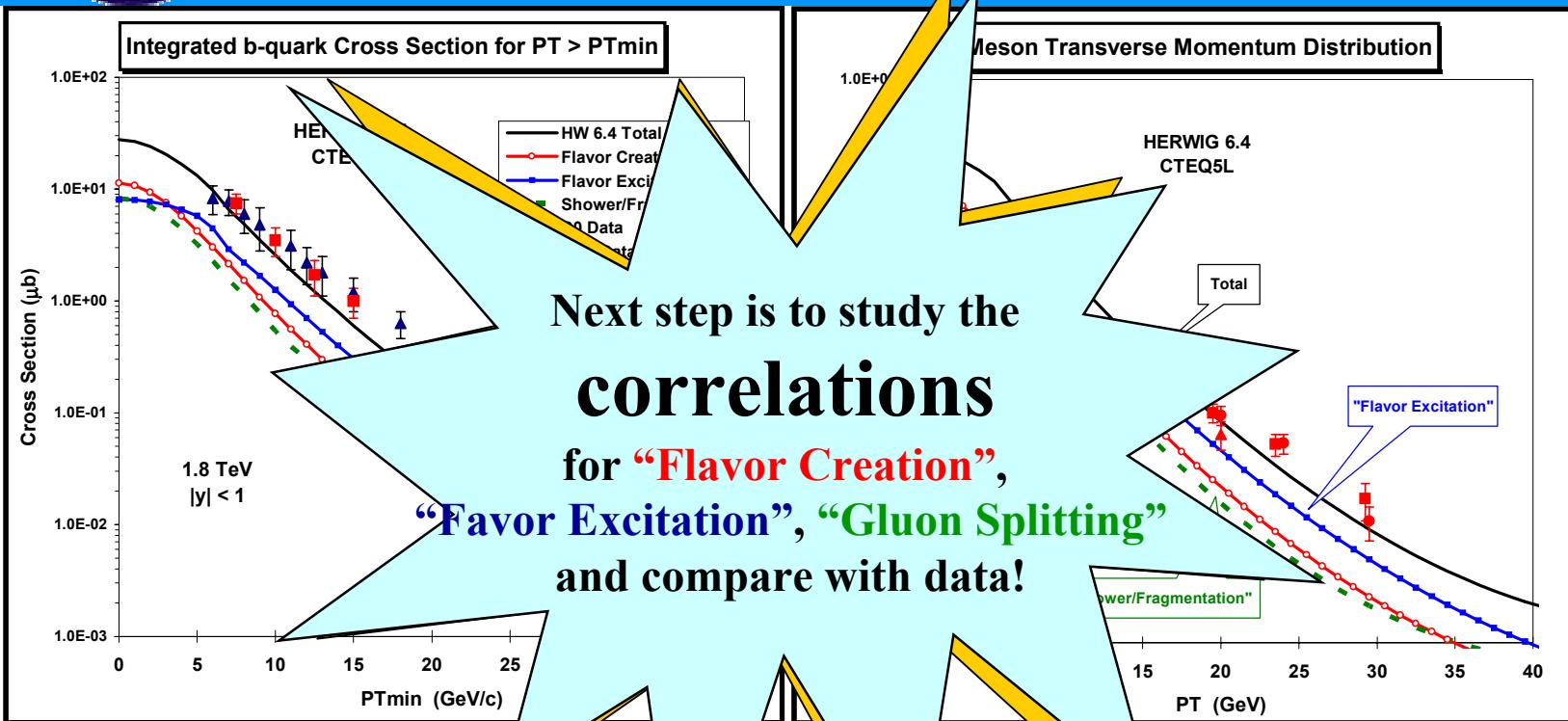
B⁺ Meson Cross Section



- Data on the integrated b-quark cross section ($\text{PT} > \text{PT}_{\text{min}}, |y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of HERWIG 6.4 (CTEQ5L).
- Data on the B^+ meson differential cross section ($|y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of HERWIG 6.4 (CTEQ5L).



B⁺ Meson Cross Section



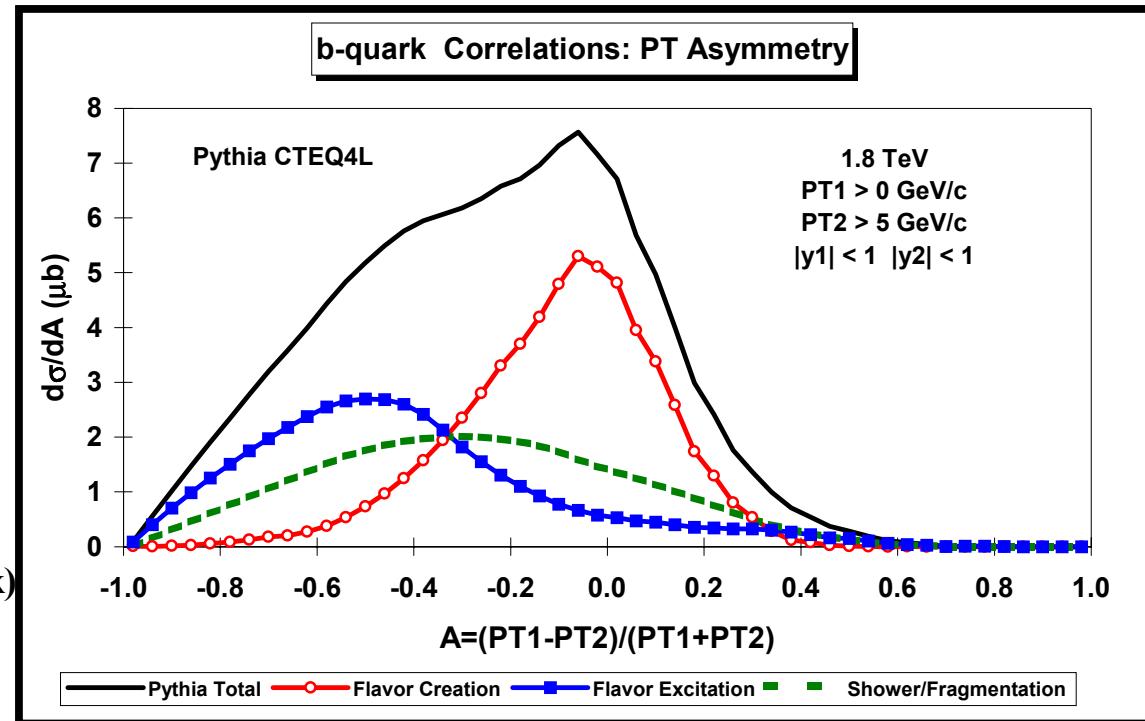
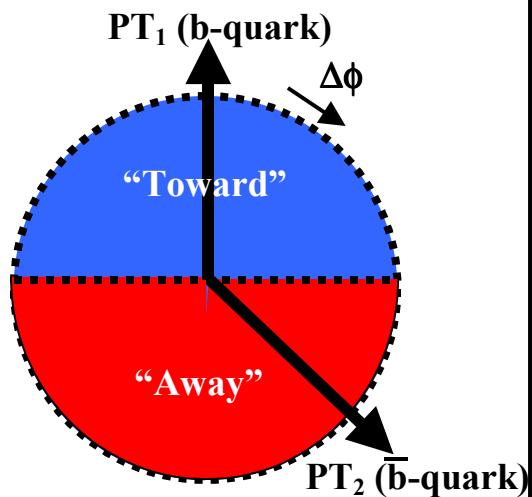
- Data on the integrated b-quark cross section with the QCD Monte-Carlo model predictions of HERWIG 6.4 (CTEQ5L).
- Data on the B⁺ meson differential cross section ($|y| < 1$) at 1.8 TeV compared with the QCD Monte-Carlo model predictions of HERWIG 6.4 (CTEQ5L).



PT Asymmetry



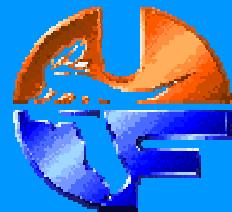
$$A = (PT_1 - PT_2) / (PT_1 + PT_2)$$



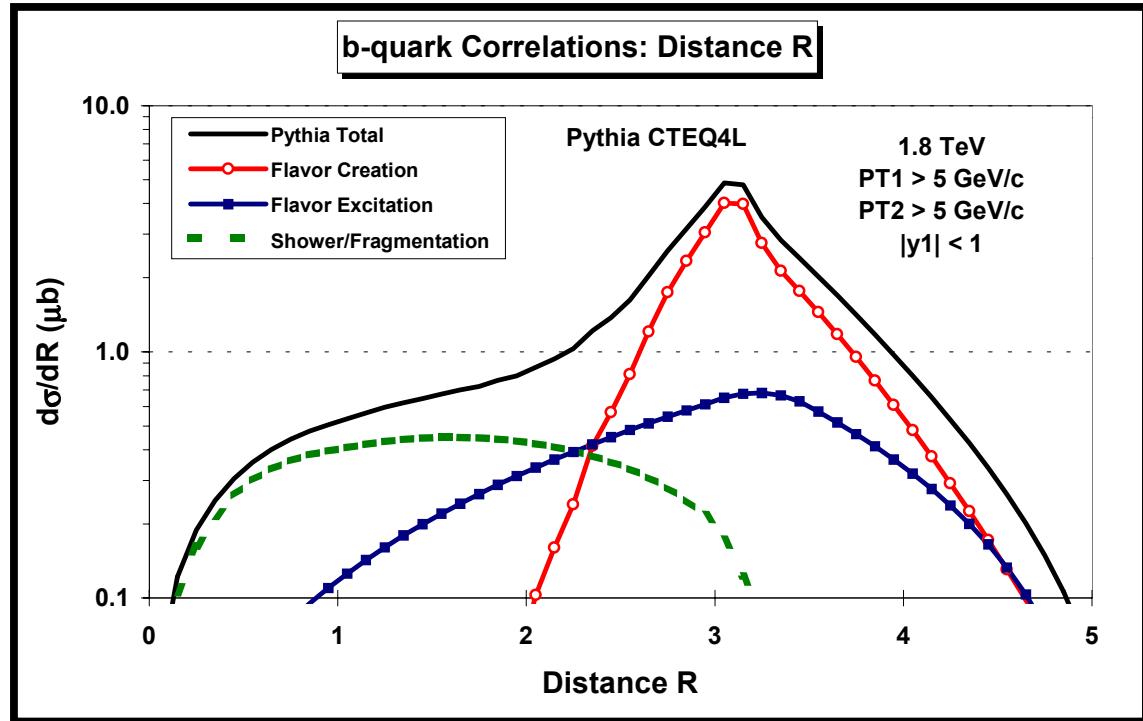
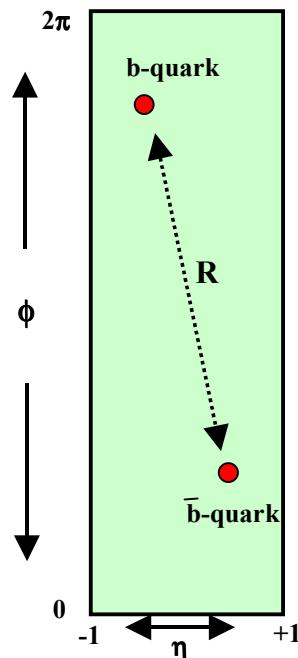
- Predictions of PYTHIA 6.158 (CTEQ4L, PARP(67)=1) for the asymmetry $A = (PT_1 - PT_2) / (PT_1 + PT_2)$ for events with a b-quark with $PT_1 > 0$ GeV/c and $|y_1| < 1.0$ and a bbar quark with $PT_2 > 5$ GeV/c and $|y_2| < 1.0$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dA$ (μb) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



Distance R in η - ϕ Space



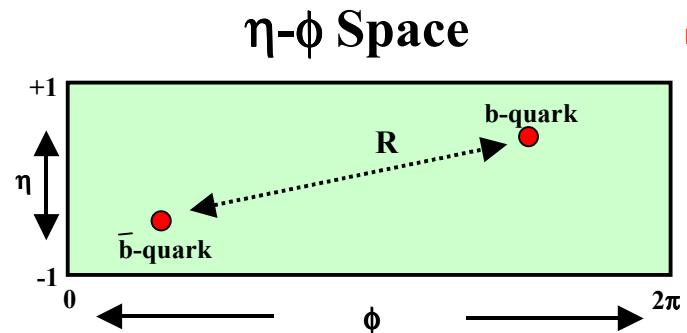
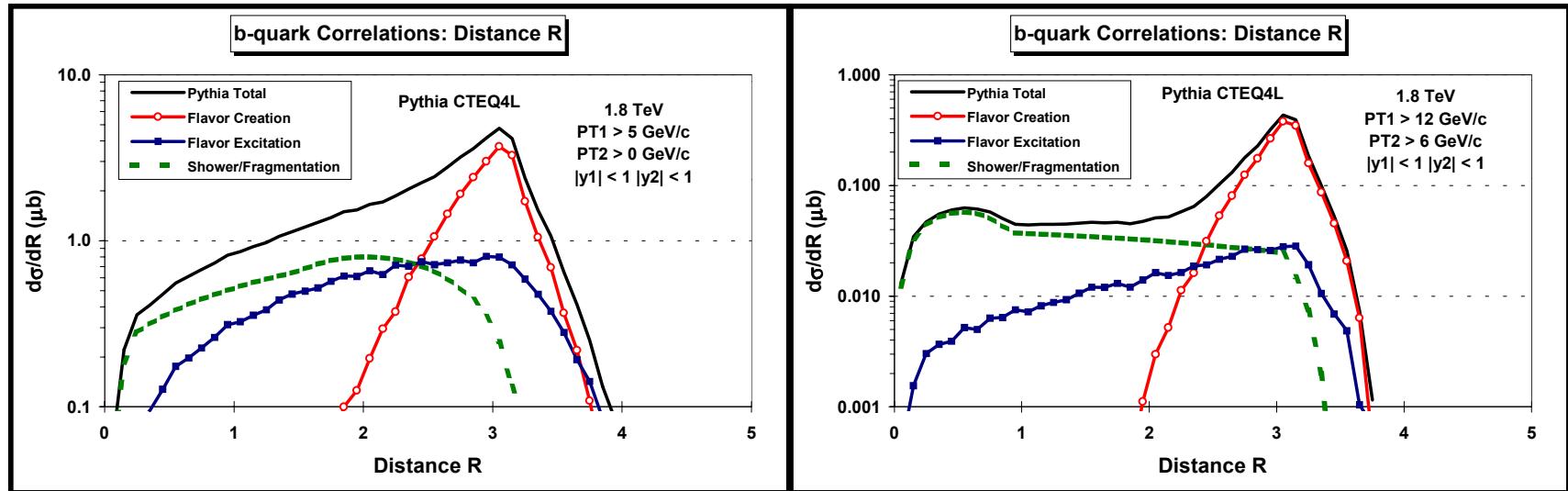
η - ϕ Space



- Predictions of PYTHIA 6.158 (CTEQ4L, PARP(67)=1) for the distance, R, in η - ϕ space between the b and bbar-quark with $PT_1 > 5 \text{ GeV}/c$, $PT_2 > 5 \text{ GeV}/c$, and $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dR$ (μb) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



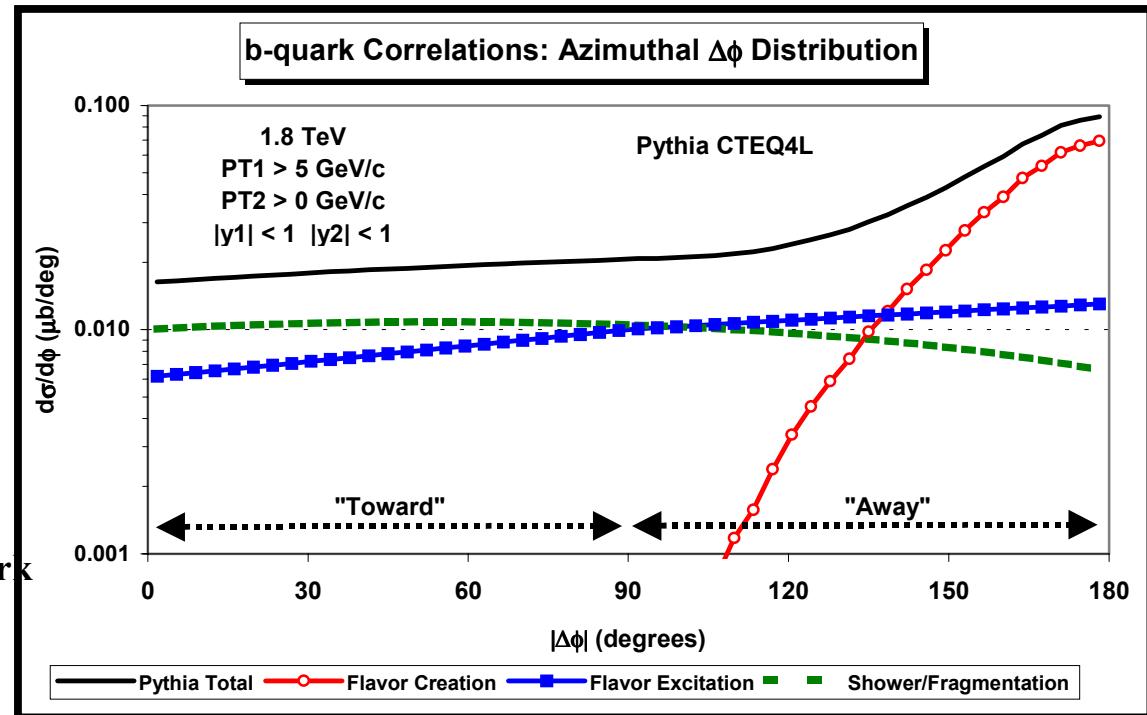
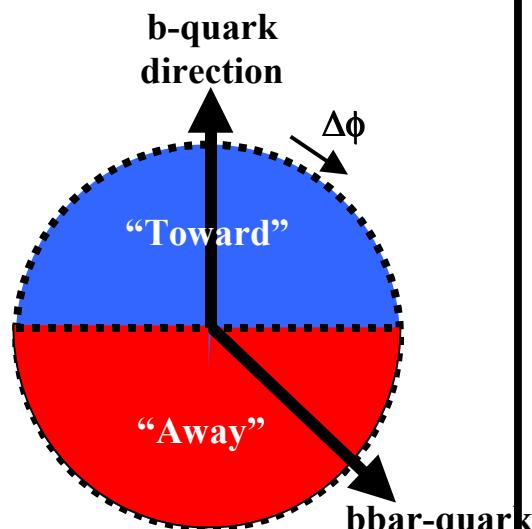
Distance R in η - ϕ Space



→ Predictions of PYTHIA 6.158 (CTEQ4L, PARP(67)=1) for the distance, R, in η - ϕ space between the b and \bar{b} -quark with $|y_1| < 1$ and $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dR$ (μb) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



Azimuthal Correlations



- Predictions of PYTHIA 6.158 (CTEQ4L, PARP(67)=1) for the azimuthal angle, $\Delta\phi$, between a b-quark with $PT_1 > 5 \text{ GeV}/c$ and $|y_1| < 1$ and a bbar-quark with $PT_2 > 0 \text{ GeV}/c$ and $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta\phi (\mu\text{b}/\text{deg})$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.

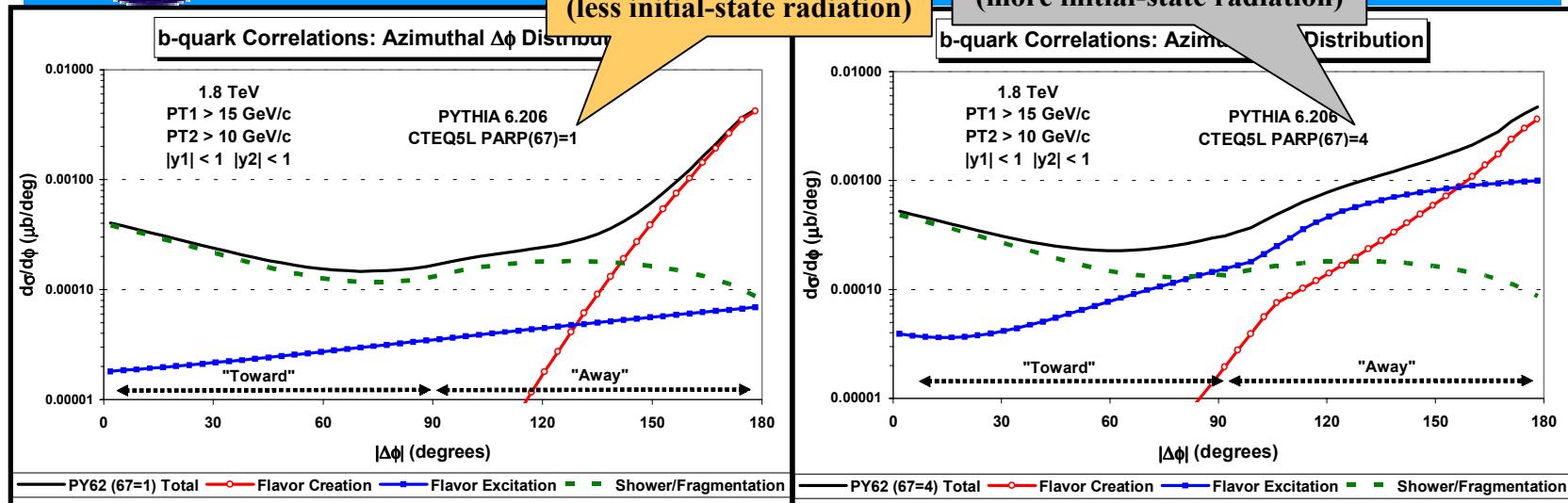


Azimuthal Correlations

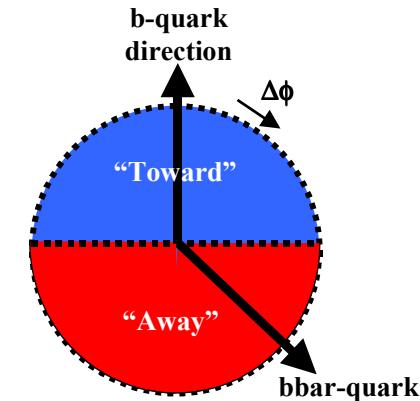


New PYTHIA default
(less initial-state radiation)

Old PYTHIA default
(more initial-state radiation)



- ▶ Predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for the azimuthal angle, $\Delta\phi$, between a b-quark with $PT_1 > 15 \text{ GeV}/c$, $|y_1| < 1$ and bbar-quark with $PT_2 > 10 \text{ GeV}/c$, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta\phi (\mu\text{b}/^{\circ})$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



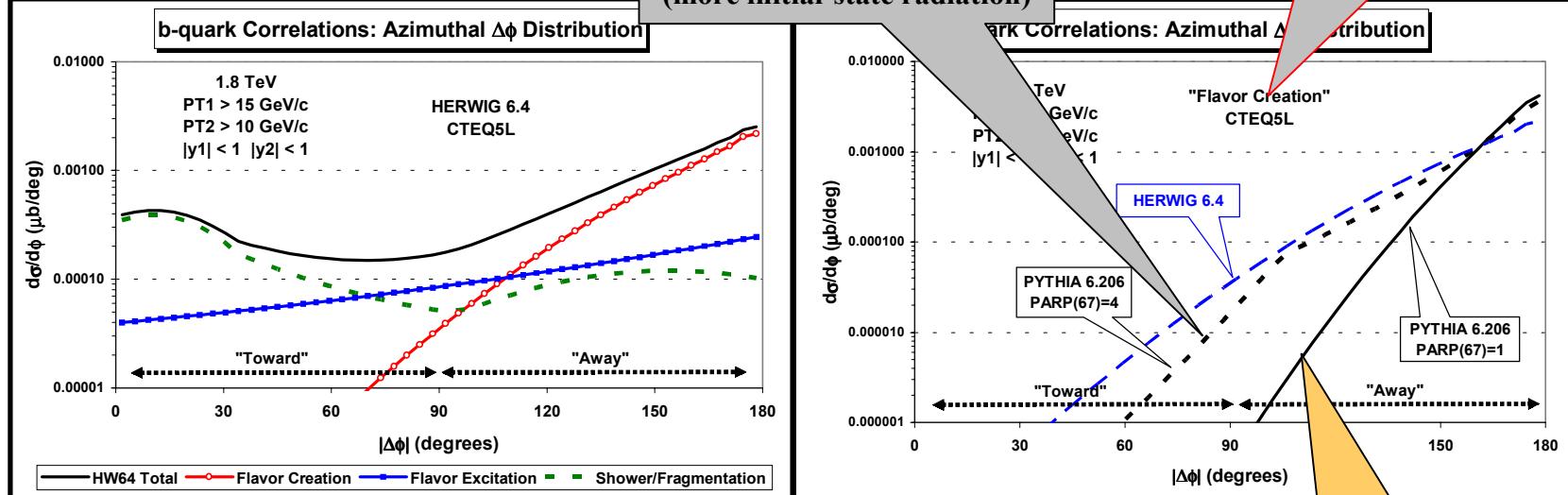


Azimuthal Correlations

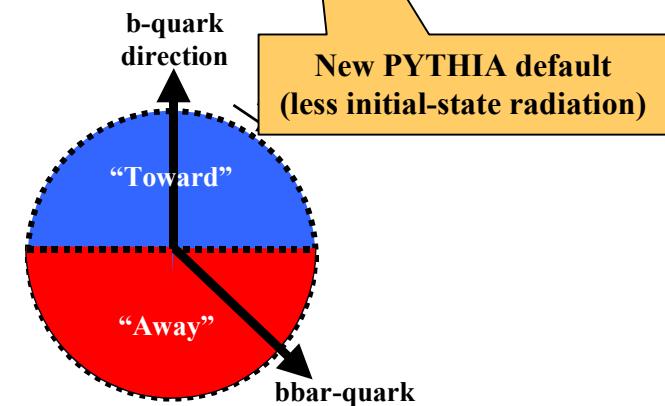


“Flavor Creation”

Old PYTHIA default
(more initial-state radiation)



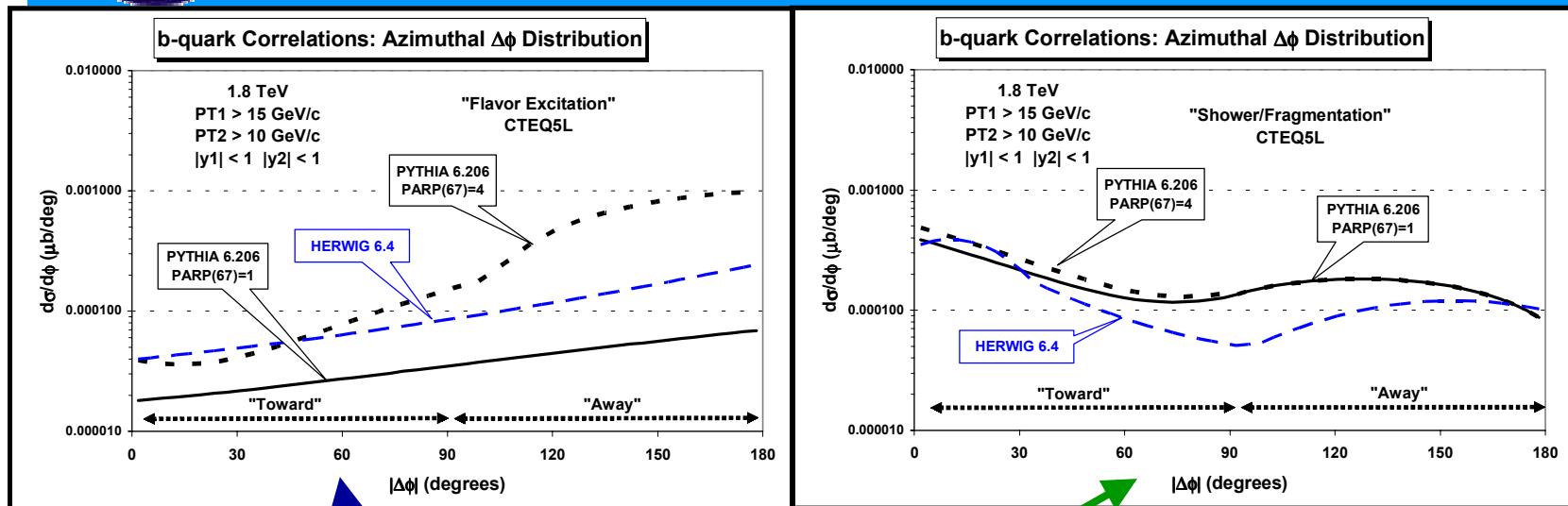
- Predictions of HERWIG 6.4 (CTEQ5L) for the azimuthal angle, $\Delta\phi$, between a b-quark with $PT_1 > 15 \text{ GeV}/c$, $|y_1| < 1$ and bbar-quark with $PT_2 > 10 \text{ GeV}/c$, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta\phi (\mu\text{b}/^0)$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



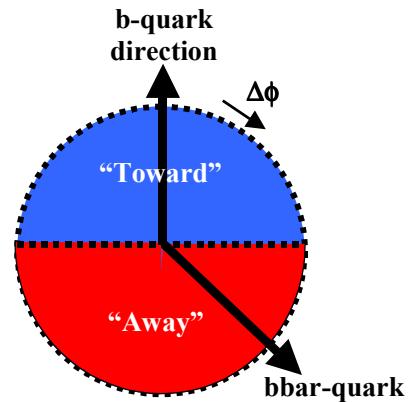
New PYTHIA default
(less initial-state radiation)



Azimuthal Correlations



- Predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) and HERWIG 6.4 (CTEQ5L) for the azimuthal angle, $\Delta\phi$, between a b-quark with $\text{PT}_1 > 15 \text{ GeV/c}$, $|y_1| < 1$ and bbar-quark with $\text{PT}_2 > 10 \text{ GeV/c}$, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta\phi$ ($\mu\text{b}/^\circ$) for flavor excitation, and shower/fragmentation.



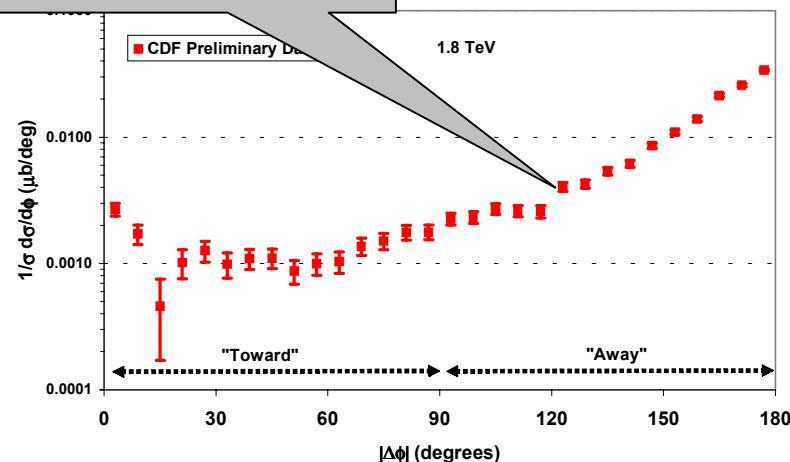


CDF Run I Analysis Azimuthal Correlations

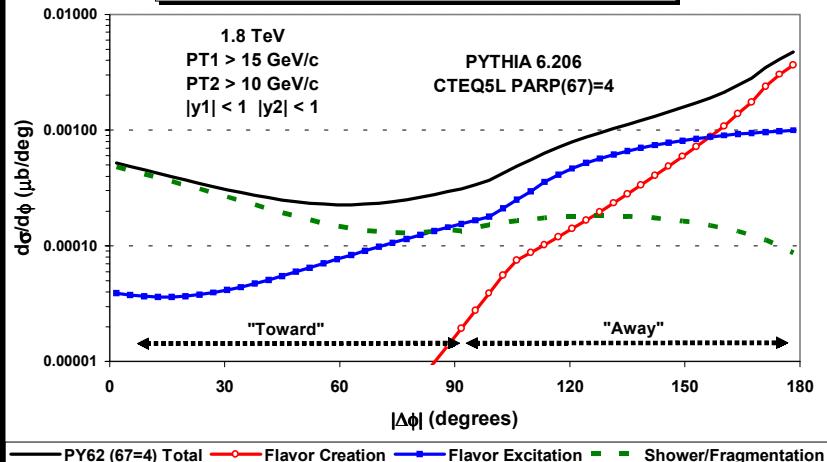


See talk by Kevin Lannon
at DPF2002

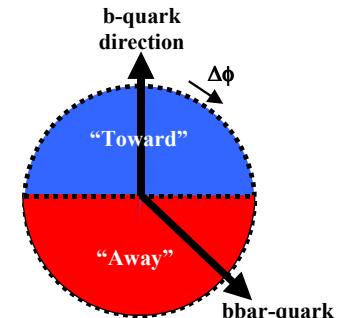
Azimuthal $\Delta\phi$ Distribution



b-quark Correlations: Azimuthal $\Delta\phi$ Distribution



- Run I preliminary uncorrected CDF data for the azimuthal angle, $\Delta\phi$, between a b-quark $|y_1| < 1$ and bbar-quark $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV.
- Warning!** Can compare theory with data only after detector simulation (this now has been done!).



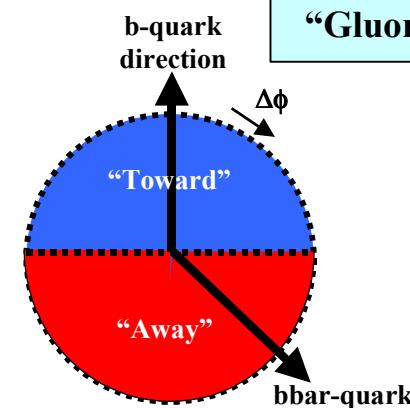


CDF Run 1 Analysis

Azimuthal Correlations

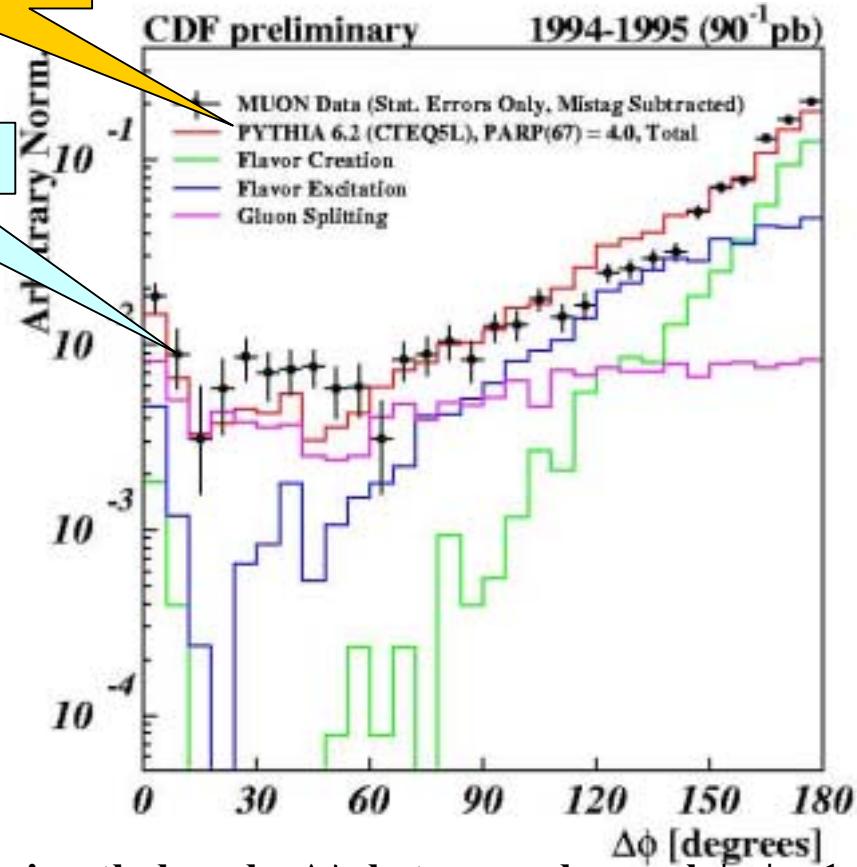


PYTHIA Tune A



"Gluon Splitting"!

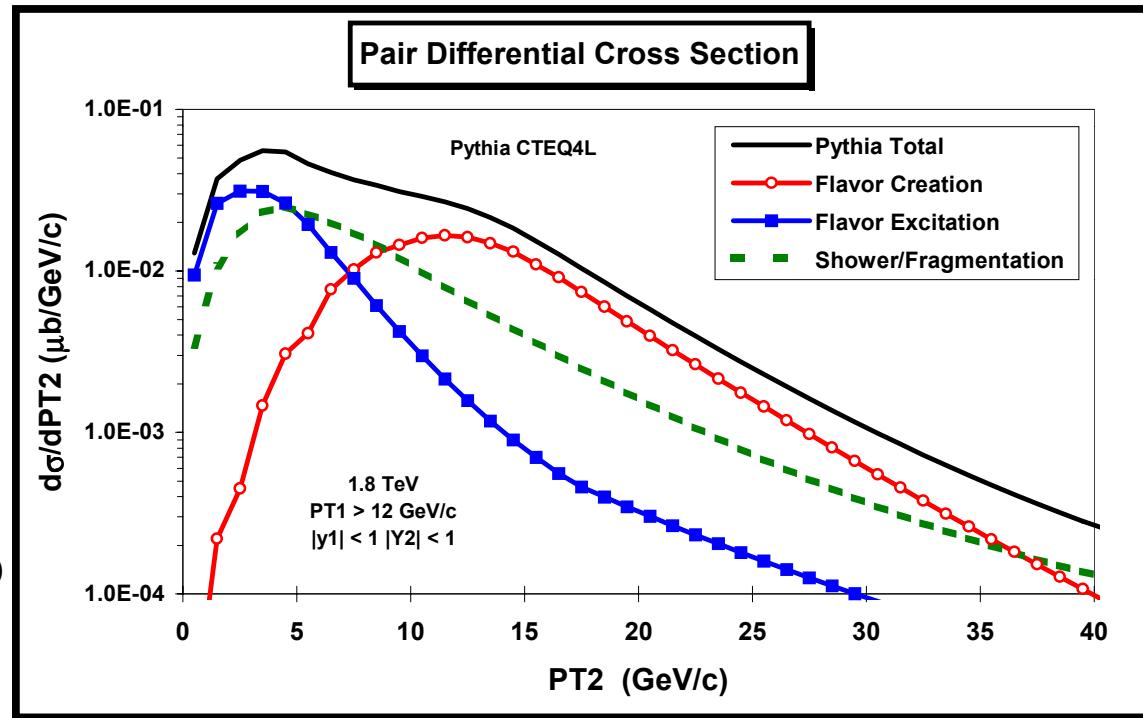
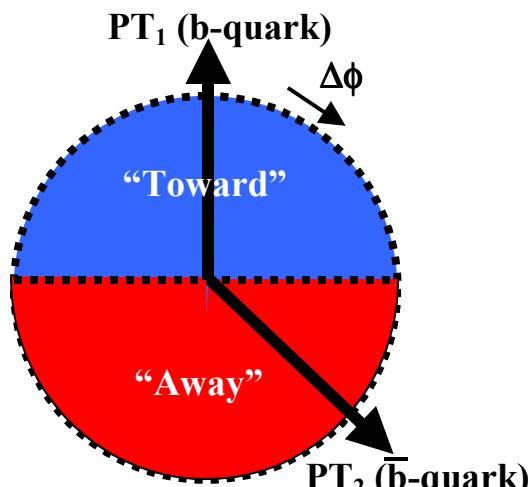
See the next talk
by Kevin Lannon!



- Run 1 preliminary CDF data for the azimuthal angle, $\Delta\phi$, between a b-quark $|y_1| < 1$ and bbar-quark $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV compared with PYTHIA Tune A after detector simulations.



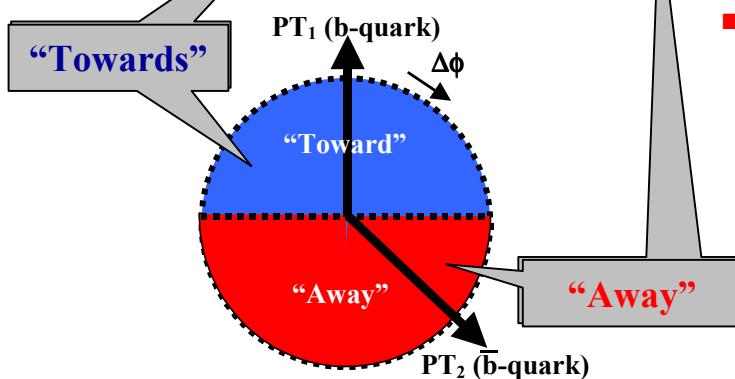
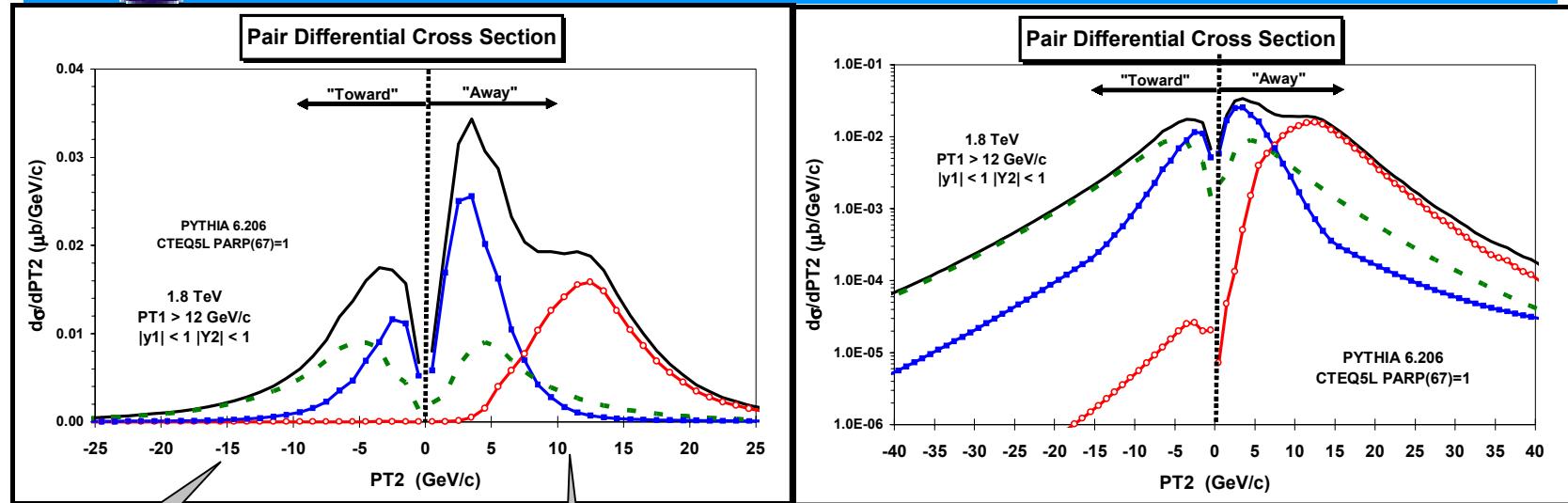
Pair Differential Cross Section



- Predictions of PYTHIA 6.158 (CTEQ4L, PARP(67)=1) for the transverse momentum, PT_2 , of a $b\bar{b}$ -quark with $|y_2| < 1.0$ for events with a b -quark with $PT_1 > 12 \text{ GeV}/c$ and $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dPT_2$ ($\mu\text{b}/\text{GeV}/c$) for **flavor creation**, **flavor excitation**, **shower/fragmentation**, and the resulting total.



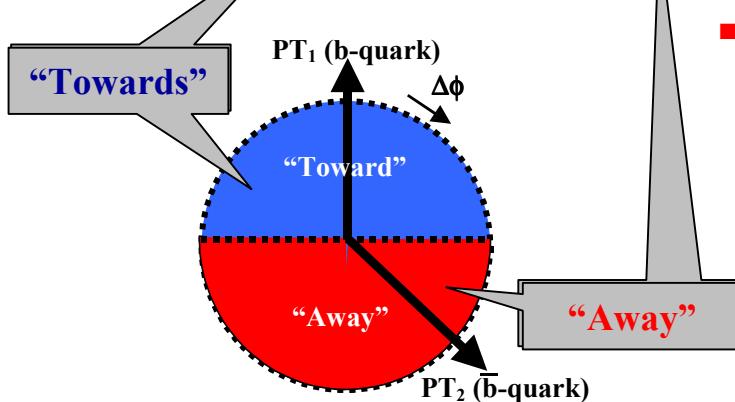
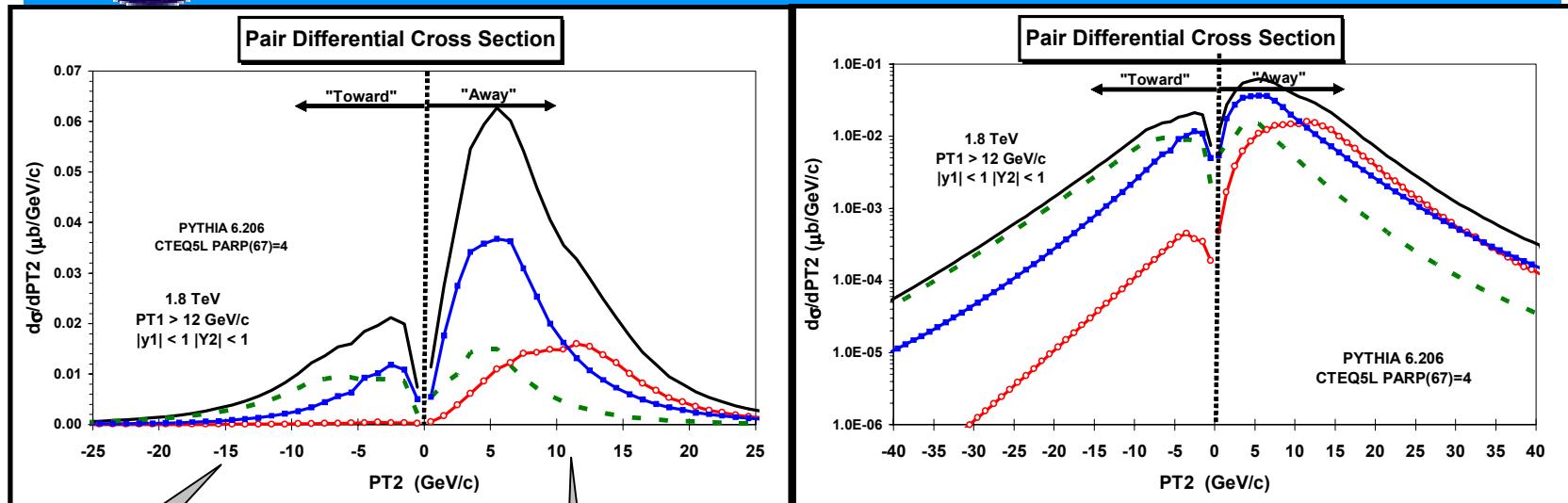
“Toward” and “Away” Pair Differential Cross Section



► Predictions of PYTHIA 6.206 (CTEQ5L, PARP(67)=1) for the transverse momentum, PT_2 , of a bbar-quark with $|y_2| < 1.0$ for events with a b-quark with $PT_1 > 12 \text{ GeV}/c$ and $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dPT_2 (\mu\text{b}/\text{GeV}/c)$ for the "toward" and "away" region of $\Delta\phi$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



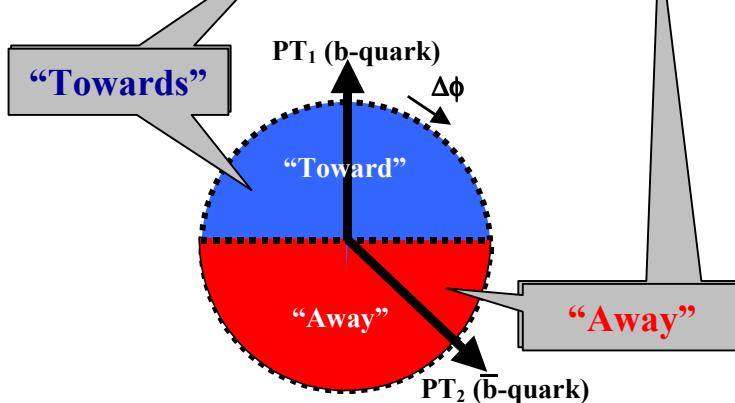
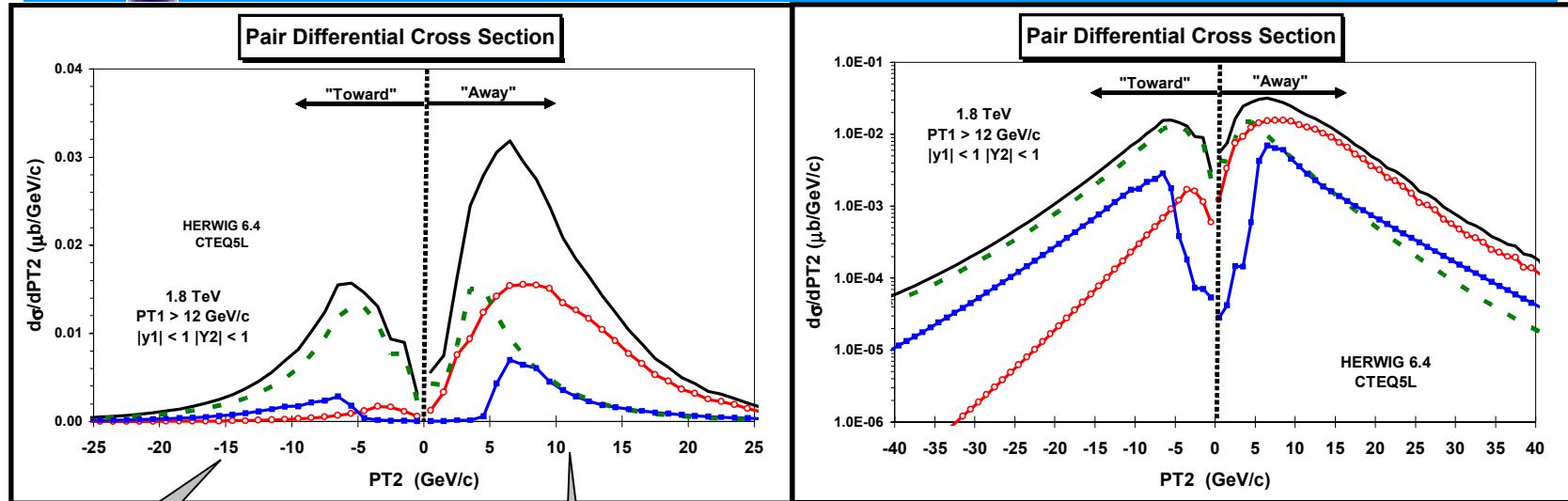
“Toward” and “Away” Pair Differential Cross Section



→ Predictions of PYTHIA 6.206 (CTEQ5L, PARP(67)=4) for the transverse momentum, PT_2 , of a $b\bar{b}$ -quark with $|y_2| < 1.0$ for events with a b -quark with $PT_1 > 12 \text{ GeV}/c$ and $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dPT_2 (\mu b/\text{GeV}/c)$ for the "toward" and "away" region of $\Delta\phi$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



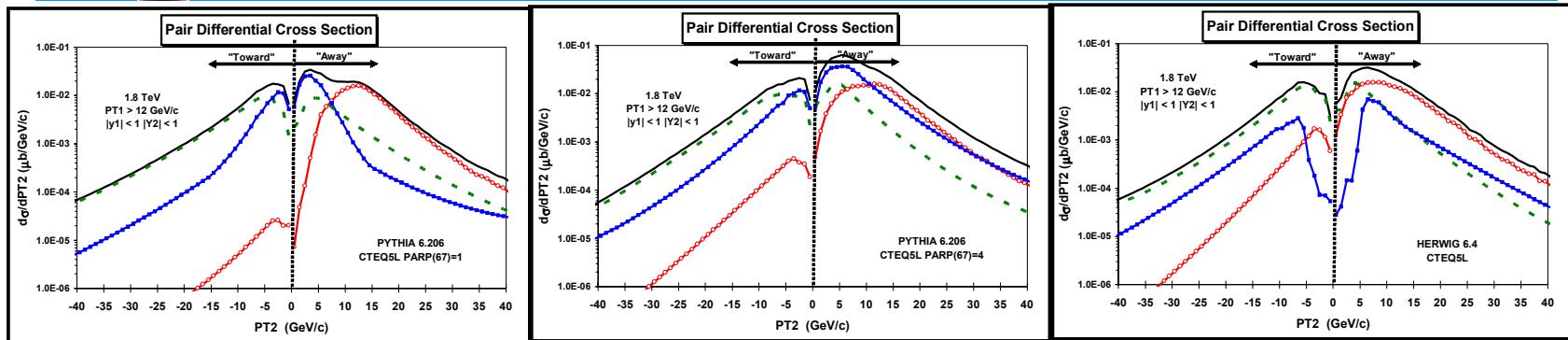
“Toward” and “Away” Pair Differential Cross Section



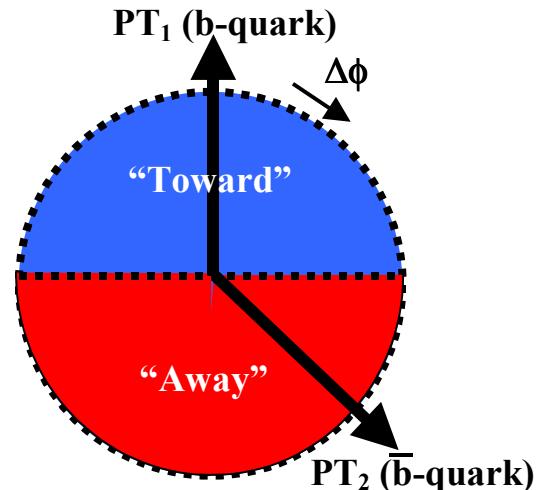
→ Predictions of HERWIG 6.4 (CTEQ5L) for the transverse momentum, PT_2 , of a $b\bar{b}$ -quark with $|y_2| < 1.0$ for events with a b -quark with $\text{PT}_1 > 12 \text{ GeV}/c$ and $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\text{PT}_2 (\mu\text{b}/\text{GeV}/c)$ for the "toward" and "away" region of $\Delta\phi$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.



“Toward” and “Away” Pair Differential Cross Section



- ▶ Predictions of PYTHIA 6.206 (CTEQ5L) PARP(67)=1 and PARP(67)=4 and HERWIG 6.4 (CTEQ5L) for the transverse momentum, PT_2 , of a bbar-quark with $|y_2| < 1.0$ for events with a b-quark with $PT_1 > 12 \text{ GeV}/c$ and $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/dPT_2 (\mu\text{b}/\text{GeV}/c)$ for the “toward” and “away” region of $\Delta\phi$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.

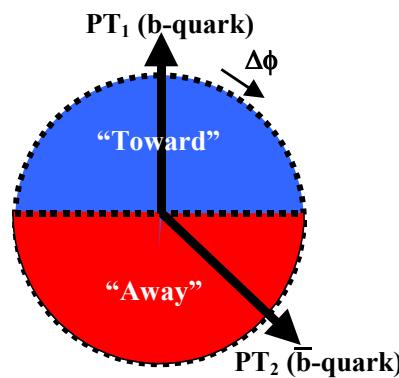
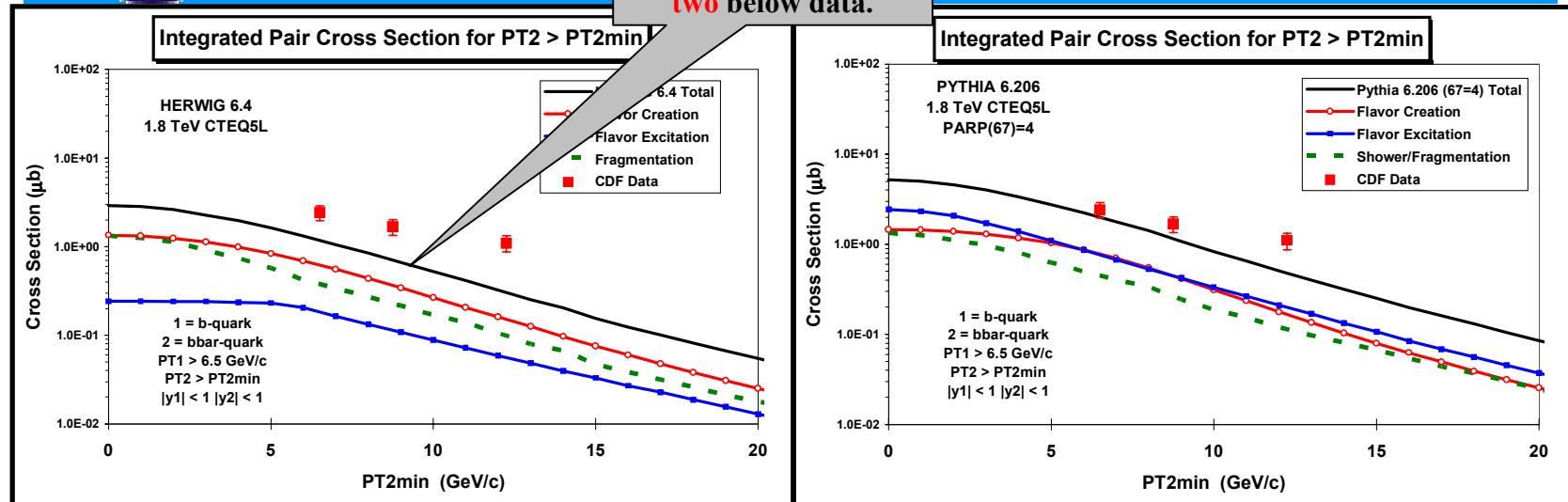




Integrated Pair Cross Section



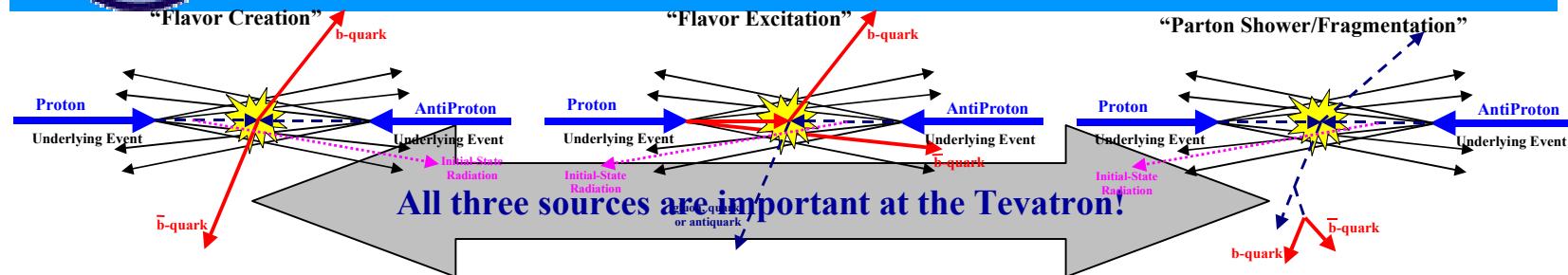
HERWIG a factor of
two below data.



- Predictions of PYTHIA 6.206 (CTEQ5L, PARP(67)=4) and HERWIG 6.4 (CTEQ5L) for the integrated pair cross section for a bbar-quark with $PT_2 > PT_{2\min}$, $|y_2| < 1.0$ for events with a b-quark with $PT_1 > 6.5 \text{ GeV}/c$, $|y_1| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $\sigma(\mu\text{b})$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.
- Important to see the data at the meson level as well as the quark level and both separated into the “toward” and “away” region!



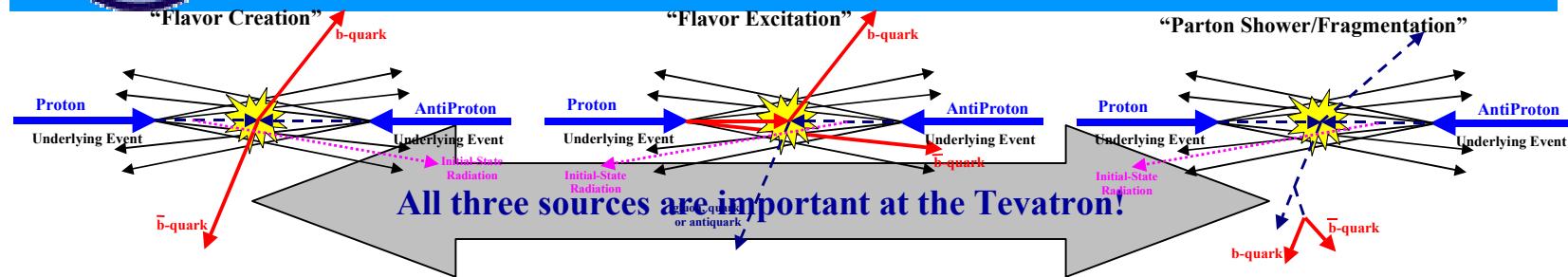
Summary & Conclusions



- The QCD “leading-log” Monte-Carlo models do a fairly good qualitative job in describing the b-quark data at the Tevatron. **The QCD “leading-log” Monte-Carlo models do a much better job fitting the b-quark data than most people realize!**
- **Much more Run 2 CDF data is on the way!** In particular, we should be able experimentally to isolate the individual contributions to b-quark production by studying b-bbar correlations and we will find out in much greater detail how well the QCD Monte-Carlo models actually describe the data.
- **Personal Remark:** I do not like it when the experimenters extrapolate to the parton level and publish parton level results. The parton level is not an observable! Experiments measure hadrons & leptons! To extrapolate to the parton level requires making additional assumptions that may or may not be correct (*and often the assumptions are not clearly stated or are very complicated*). However, I understand why this happens (and I cannot stop it) so I suggest that the experimenters always publish the corresponding hadron level result along with their parton level extrapolations.
- **Personal Remark:** I do not like it when theorists attempt to compare parton level calculations with experimental data. Hadronization and initial/final-state radiation effects are almost always important and hence parton level calculations should be embedded within a parton-shower/hadronization framework (e.g. HERWIG or PYTHIA).



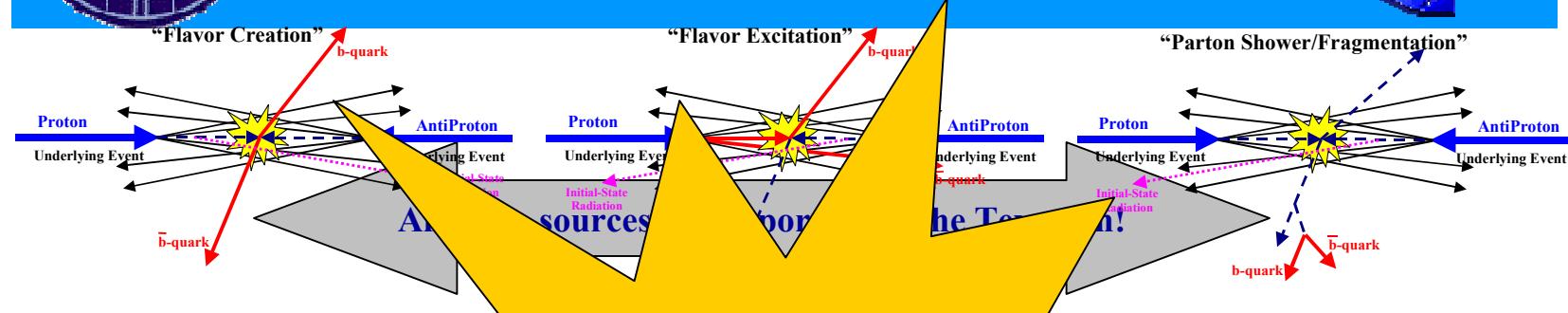
Summary & Conclusions



- The QCD “leading-log” Monte-Carlo models do a fairly good qualitative job in describing the b-quark data at the Tevatron. **The QCD “leading-log” Monte-Carlo models do a much better job fitting the b-quark data than most people realize!**
- **Much more Run 2 CDF data is on the way!** In particular, I am trying to isolate experimentally to isolate the individual contributions to b-quark production by solving correlations and we will find out in much greater detail how well the QCD Monte-Carlo models actually describe the data! This is now finally being done!
- **Personal Remark:** I do not like it when the experiments extrapolate to the parton level from parton level results. The parton level is not an observable! Experiments measure hadrons! To extrapolate to the parton level requires making additional assumptions that may or may not be correct (*and often the assumptions are not clearly stated or are very complicated*). However, I understand why this happens (and I cannot stop it) so I suggest that the experimenters always publish the corresponding hadron level result along with their parton level extrapolations.
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Summary & Conclusions



- The QCD “leading-log” Monte Carlo calculations do a better job in describing the b-quark data than most other calculations.
- Much more Run 2 CDF data is available, so we can study the individual contributions to the total cross section in much greater detail here.
- **Personal Remark:** I do not like it when theorists extrapolate to the parton level results. That is, they often attempt to compare parton level calculations with experimental data. Hadronization and initial-state/final-state radiation effects are almost always important and hence parton level calculations should be embedded within a parton-shower/hadronization framework (e.g. HERWIG or PYTHIA).

The next step is to compare with next-to-leading order calculations embedded within HERWIG or PYTHIA!

This is now finally being done! We will be able experimentally to isolate correlations and we will find that we can describe the data to the parton level. Measurements measure hadron level leptons! Options that may or may not be complicated). However, I suggest that the experimenter always publish parton level extrapolations.